PERFORMANCE EVALUATION OF ASPHALT BINDER USING WASTE TIRE RUBBER, WASTE COOKING OIL AND WASTE ENGINE OIL

By

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DEDICATION

I dedicate this work to my parents,

who have always provided me with inspiration, love,

and wisdom.

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ABSTRACT

Most of the roads in Pakistan are built using bituminous material (asphalt). Bitumen is susceptible to failures due to increased axle weights, heavy traffic, and harsh climatic conditions. As a result, bitumen's performance-related qualities, such as resistance to permanent deformation, low-temperature cracking, wear, stripping, and ageing need to be addressed (Abrahim, 2012). It has revealed that bitumen and asphalt can fulfil pavement requirements by incorporating certain additives. Crumb Rubber Modified Bitumen is one such effort that improves bitumen's elastic response at higher temperatures (Kamal et al., 2016).

This research is based on the performance assessment of hot mix asphalt (HMA) by incorporating different percentages of WCO and WEO in combination with WRT in place of the ideal bitumen content. Aside from enhancing pavement construction and exploring innovative ways to improve it, the study also focuses on waste management which has been a growing problem throughout the world. According to the Environmental Protection Agency (EPA), Pakistan generates about 20 million tonnes of solid waste every year, with the rate increasing by 2.4 per cent each year (Malik, 2019). It also analyses the impact on the cost of using the waste materials as possible replacement materials.

To achieve the goals of the research, several laboratory tests including penetration, ductility, softening point and rotational viscosity test were undertaken on virgin bitumen and modified bitumen. In addition, Performance tests namely the Indirect Tensile Strength test for Moisture Susceptibility and Resilient Modulus were calculated. All physical and performance test result shows that about 16% of bitumen can be replaced with WCO or

WEO and WRT powder. Modified bitumen carrying 4% WEO and 12 % WRT shows massive resistance to moisture. Cost Analysis of virgin bitumen and modified bitumen concluded that utilizing modified bitumen can result in the reduction of cost used per Km by almost 10-15%.

Keywords: Waste cooking oil, waste rubber tire, waste engine oil, Resilient modulus, EPA

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WCO	Waste cooking oil
WEO	Waste engine oil
WRT	Waste rubber tire
RV	Rotational Viscosity
SARA	Saturates, Asphaltenes, Resins, and Aromatics
OBC	Optimum bitumen content
JMF	Job mix formula
HMA	Hot mix asphalt
TSR	Tensile strength ratio
NHA	National Highway Authority
ITS	Indirect tensile strength
ASTM	Ameriacn society of testing materials
AASHTO	American association of states highways and transportation official.

CHAPTER 1: INTRODUCTION

1.1 Background

The transportation system is also an essential part of modern society's well-being. The economic and social necessity of a dependable and robust transportation system has prompted much research into the systems that cause its susceptibility and strategies, leading to a robust and resilient and reducing the effects of disruptions. Road infrastructure is essential to society's functioning in both developed and developing countries. The road system serves as a lifeline for rescuing people and economic values and repairing and restoring other infrastructure systems when other infrastructure systems are disrupted. (Mattsson and Jenelius, 2015).

Road networks and buildings have been built from the early Roman era to the national road system in the US. The resources and the materials utilised in infrastructure projects have evolved with time. Pavements are divided into two categories: flexible and rigid pavement.

Most of the roads in Pakistan are built using bituminous material (asphalt). Asphalt roads are prevalent in urban areas, and a significant share of its budgetary provisions has been spent on road network rehabilitation in the country. Bitumen is classified into two groups in the road construction sector. (Honarmand, Tanzadeh and Beiranvand, 2019):

- Bitumen (mineral pitch)
- The by-product of crude oil distillation.

Bitumen is a practically inert, sticky and impermeable compound which is a processed form of crude oil. It can almost entire dissolve in methylbenzene and stiff or solidifies at 25-28 degrees Celsius (room temperature) according to European specifications (EN 12597). It is widely known that bitumen's original features and crude oil characteristics significantly depend on its production and processing procedures. By using good-quality crude oils and by following correct distillation procedures, Bitumen characteristics can be improved. Bitumen yields are generally higher when crude oil is heavier (Porto et al., 2019). However, increased axle weights, heavy traffic, harsh climatic conditions, and construction failures during the previous decade necessitated the need to improve the qualities of the base bitumen. As a result, bitumen's performance-related qualities, such as resistance to permanent deformation, low-temperature cracking, wear, stripping, and ageing need to be addressed (Abrahim, 2012).

1.2 Problem Statement

India is a neighbouring country with a similar highway construction system. It almost faces similar issues (increased axle weights, heavy traffic, harsh climatic conditions, and construction failures during the previous decade). Having an identical environment as in Pakistan has revealed that bitumen and asphalt can fulfil pavement requirements by incorporating certain additives. Crumb Rubber Modified Bitumen is one such effort that improves bitumen's elastic response at higher temperatures (Kamal et al., 2016).

The application of modified bitumen has been claimed to provide a solution for lowering the maintenance rate, as a result, treatments last longer. Furthermore, at high temperatures, bitumen modification enhances the resistanc against permanent deformation of asphalt concrete. This could be accomplished by altering specific physical and rheological properties. For instance, raising the elastic component of the bitumen, so lowering the viscous component, resulting in a decrease in permanent strain, or stiffening the bitumen so that the overall visco-elastic response of the asphalt is reduced.(Kamal et al., 2016).

Changing bitumen properties has an impact on the asphalt mix. Asphalt is called a bituminous material because it contains bitumen. Therefore, changing the properties of bitumen changes the properties of the asphalt mixture. The thesis investigates impact of bitumen modification on binder mixture.

1.3 Research Objectives

- To investigate the physical properties of bitumen using WEO (Waste Engine Oil), ground WRT (Waste Tire Rubber) and WCO (Waste Cooking Oil) and to optimize the blend.
- To investigate the effects of WEO/WCO and crumb rubber on the viscosity of the binder.
- To analyze the impact of modified bitumen on the performance of HMA
- To provide cost analysis for modified bitumen mixture

1.4 Scope of Research

As per its performance, bitumen is considered a perfect construction material for pavements, but various conditions such as traffic and weather affect its efficiency. Therefore, to improve its various properties, different modifications have been studied to achieve the required level of performance. The addition of thermoplastic or elastomeric polymers to bitumen is a typical method of bitumen modification. However, just a few studies on bitumen blends with multiple modifiers look to ensure a positive impact on its engineering characteristics. This research aims to continue the same research already being carried out to improve materials used in roads, etc. This research will explore waste materials as modifiers in bitumen and assess their impact on asphalt. The matrix for various physical tests is formulated hereunder:

Table 1-1 Test matrix for the physical test of bitumen

Type of Sample	Bitumen Replaced (%)	Penetration test	Softening Point test	Ductility	Specific Gravity Test	Total
Virgin Bitumen	0	3	3	3	3	12
Virgin Bitumen + WCO	2	3	3	3	3	12
	4	3	3	3	3	12
	6	3	3	3	3	12
Virgin Bitumen +WEO	2	3	3	3	3	12
	4	3	3	3	3	12
	6	3	3	3	3	12
Virgin Bitumen + WRT	4	3	3	3	3	12
	6	3	3	3	3	12
	8	3	3	3	3	12
	10	3	3	3	3	12
	12	3	3	3	3	12
Virgin Bitumen +4%WCO+WRT	8	3	3	3	3	12
	12	3	3	3	3	12
	16	3	3	3	3	12
	8	3	3	3	3	12

Virgin Bitumen+4%WEO+WRT	12	3	3	3	3	12
	16	3	3	3	3	12
Total		54	54	54	54	216

The matrix for viscosity tests is formulated hereunder:

Table 1-2 Test Matrix for viscosity test

Type of Sample	Replaced Bitumen	Unaged	RTFO aged	Total
Virgin Bitumen	0	3	3	6
Virgin Bitumen + WCO	4	3	3	6
Virgin Bitumen +WEO	4	3	3	6
Virgin Bitumen + WRT	12	3	3	6
Virgin Bitumen +4%WCO+12WRT	16	3	3	6
Virgin Bitumen+4%WEO+12WRT	16	3	3	6
Total		18	18	36

The matrix for the performance test is formulated hereunder:

Table 1-3 Test matrix for performance test of asphalt

Type of Sample	Resilient Modulus	ITS	Moisture Susceptibility	Total
Virgin Bitumen	3	3	3	9
Virgin Bitumen +4%WCO+12WRT	3	3	3	9
Virgin Bitumen+4%WEO+12WRT	3	3	3	9
Total	9	9	9	27

Apart from improving pavement construction and researching new combinations to improve it, Waste management has become an increasing concern worldwide. Pakistan creates over 20 million tons of solid garbage annually, according to the Environmental Protection Agency (EPA), and this rate is growing by 2.4 per cent each year (Malik, 2019). These all-waste materials add to landfills, and this research will help promote UN SDGs in Pakistan.

1.5 Thesis Flow

This Research Document is divided into five Segments as given below:

Chapter 1 presents the subject matter and explains its background. It explains how economic and social development is dependent on a transportation system of a country. Road networks are an integral part of the transport system and the majority of roads in Pakistan are built using bituminous material. Modification of bituminous material can improve the quality of roads. This chapter also lays out the objectives and scope of this research.

Chapter 2 contains the literature review of this thesis. Literature mainly focuses on the material being used in the construction of roads in Pakistan and how the quality of material impacts the quality of roads. Moreover, it talks about bitumen modification and its impact which has been studied by different researchers in the recent past. Chapter 2 also sheds light on use of WRT, WEO and WCO as modifiers by researchers in the past.

Chapter 3 This chapter includes details about the materials used in this research and the research methodology. The primary materials include 60/70 penetration grade asphalt binder, waste engine oil, waste cooking oil and waste tire rubber and chemical. The testing approach includes both the physical properties and the viscoelastic parameters to be evaluated. Performance testing of asphalt to be conducted by using the optimum value of waste material by replacing bitumen.

Chapter 4 Explained the results obtained from laboratory testing. All the analysis was done in finding the results.

Chapter 5 is comprised of conclusive comments based on the research finding as well as recommendations and ideas for future research studies.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The transportation sector contributes over 10% of Pakistan's GDP and more than 6% of the country's overall employment (Ministry of Planning, 2014). Both export competitiveness and economic growth are dependent on the development of Pakistan's transportation system. Identifying and solving transportation problems, especially in urban centres, is one of Pakistan's chief tasks confronting governments. In 2010, roads accounted for almost 92 per cent of passenger traffic, and 96 per cent of freight traffic in Pakistan; total inland traffic by road and rail was estimated at 325 billion passengers per kilometres (km) and 159 billion freight ton-kilometres (World Bank, 2015).

Road infrastructure is increasing every year in Pakistan, and now, thanks to China, Investment is at a record high. Pakistan is the key nation through the China-Pakistan Economic Corridor (CPEC), according to China's grand vision for the Belt and Road Initiative (BRI) in South Asia (Islam, Md Nazmul and Cansu, Esra Eymen, 2020). Our country is capitalising on its geographical location. By uniting isolated state areas into one road one Asia network, it aims at establishing an efficient and well-integrated transportation and communication infrastructure. The China-Pakistan Economic Corridor would connect Pakistan to regional nations by roads and trains, resulting in an economic boom by connecting Pakistani markets to Central Asia, the Middle East, and other regions of the world (Javed Akram, 2016). It refers to a large-scale 3000-kilometre transit corridor between China and Pakistan that spans from Kashgar, China, to Gwadar, Pakistan. It serves as a vital junction on the North-South Silk Road (Deng and Feng, 2020).

Typically, the word pavement refers simply to the surface layer. However, highway design refers to the entire thickness of the pavement, which includes the wearing (surfacing) course, base course, and sub-base course. It is a firm and durable crust built over the natural subgrade to produce a solid and levelled or flat surface for cars. It is a construction composed of overlying layers of materials over the natural subgrade, and its primary and principal function is to transmit and disperse the axle loads of cars to the subgrade. The pavement construction should provide an appropriate riding quality surface, enough skid resistance, and minimal noise pollution (Flamarz Al-Arkawazi, 2017).

There are two main types of pavements: Rigid Pavement and Flexible pavements. In this research, our focus will be on flexible pavements only. One of the major differences in the pavement types is the binder used. Flexible pavements use bitumen as binder material.

Flexible pavements are chosen over cement concrete roads because they may be reinforced and upgraded in stages as traffic increases, and their surfaces can be crushed and reclaimed for rehabilitation. Flexible pavements are also less costly in terms of initial investment and upkeep. Although rigid pavement is more expensive, it requires less maintenance and has a longer design life (Jain, Joshi and Goliya, 2013).

2.1.1 Problems with flexible pavements

In Pakistan, most of these roads are "Surface Treated," intending to upgrade to "Asphalt Concrete" for better performance and ride quality. Asphalt Concrete (also known as HMA) is made up mostly of asphalt binder and aggregate. The asphalt binder, virgin or modified asphalt, works as a glue to hold aggregate particles together. Although asphalt binder accounts for approximately 4 to 10% of the overall mix used in pavement building, it is critical in determining pavement performance (World Highways, 2016).

Excessive axle loading and over-inflation of truck tires, inappropriate design inputs for materials and climatic conditions, and the use of an empirical pavement design method, which is not truly representative of the environmental conditions, are the primary causes of premature failure of flexible pavement structures in Pakistan. Flexible pavements with hot mix asphalt concrete (AC) paving account for most road pavements globally, including in Pakistan, owing to their inexpensive initial and ongoing costs, ease of construction, excellent riding quality, and skid resistance, among other factors (AHMAD, 2011).

The tendency of asphalt to become brittle at low temperatures and soft at high temperatures is an issue in all asphalt applications. In cold regions, transverse cracking of asphaltic paving materials is a serious problem which has not been completely resolved despite many efforts (Jew et al., 1986). Temperature susceptibility refers to this change because of temperature. Some asphalts are more temperature-sensitive than others, depending on the crude oil source and refining process. Asphalt cement can be amended by adding components that boost the material's strength or change its qualities. Various additives, polymers, and other materials have been used to improve the high and low-temperature properties of asphalt compositions, as well as their toughness and durability (Al-Hadidy and Yi-qiu, 2009).

2.2 Binder Modification

Asphalt (bituminous material) is employed in various activities, including road construction. The fundamental considerations, like with concrete, are cost and durability.

Bitumen is a viscous liquid obtained from oil distillation. This substance is usually referred to as “asphalt cement” or “asphalt” in North America. A combination of tiny stones, sand, filler, and bitumen used as a road paving or roofing material is referred to as “asphalt” elsewhere (A. Claisse, 2016). Bitumen is one of the most well-known and commonly utilised building materials. Even though its components are derived from finite resources, it has long been regarded as a sustainable product because of its ability to extend usable life through reclaim, reuse, and recycling operations (M. Khatib, 2016).

Bitumen (binder) is produced by distilling crude oil. The crude oil is vaporised and then condensed in a distillation tower, with the lightest components (those with the lowest boiling points) condensing closest to the top (A. Claisse, 2016). Bitumen ties the aggregate together in the building of flexible pavements by covering the aggregate. It also aids in the strengthening of the road. However, it has low water resistance. There are anti-stripping compounds in use. Due to rapid infrastructure development, road surfaces with clean bitumen can produce bleeding in hot climates, develop cracks in cold climates, lower load-bearing capability, and cause significant damage due to increasing axle load. Modifying the material qualities of bitumen by combining it with organic synthetic polymers like rubber and plastics is a common way to increase its quality (Singhal, Yadav and Mandal, 2016).

The physical properties of bitumen have a massive effect on how asphalt behaves. Bitumen is vital for pavement’s capacity to resist heat and fatigue cracking, as well as contributing to permanent deformation (Al-Abdul Wahhab et al., 1997). The two most common distresses in road pavement are fatigue and rutting. These are primarily attributable to a rise in the number of cars, particularly those with high axle loads, environmental conditions, and construction and design flaws. As a result, the service life of asphalt pavement is impacted and will be reduced (Taher Baghaee Moghaddam, Mohamed Rehan Karim and Abdelaziz, 2011).

Modifying the physical qualities of bitumen by combining it with organic synthetic polymers like rubber and plastics is a common way to increase its quality (Singhal, Yadav and Mandal, 2016). In the recent past, several admixtures and additives were experimented with to enhance the physical characteristics of binder. Polymers, chemical modifiers, extenders, oxidants and antioxidants, hydrocarbons, and anti-stripping additives have all been used to improve bitumen performance (Porto et al., 2019).

Many mineral, organic, natural, and industrial additives are now used to improve and modify some properties of asphalt binders, such as resistance to thermal and shrinkage cracking, reduction in permanent deformation and asphalt bleeding, and reduction in hardness due to asphalt binder ageing (Ameri et al., 2011). Most of the recent research shows that polymers have been used to modify bitumen to overcome its deficiencies to perform well under different temperatures and load conditions.

2.2.1 WEO and WCO with Bitumen

Unprocessed waste oils dumped in waterways and streams have negative environmental consequences (Joni, Al-Rubaee and Al-zerkani, 2019). WEO (Waste Engine Oil) and WCO (Waste Cooking oil) have been studied as possible modifiers for bitumen in recent years.

Many investigations on WEO or WCO as asphalt rejuvenators have been conducted in recent years. Due to the molecular structure similarities between WEO and WCO and asphalt, various attempts to employ WEO and WCO as an asphalt binder have been made (Li et al., 2019). According to (Li et al., 2019), the elastic modulus, heat sensitivity, zero shear viscosity, and anti-rutting ability of WEO-modified asphalt were all decreased. However, the fatigue resistance and temperature sensitivity were increased (A.M.

Hesp and F. Shurvell, 2010) concluded that the performance of binder containing WEO content of greater than 15% is below par, especially in the case of rejuvenated Asphalt. (Fernandes, Silva and Oliveira, 2018) examined the physical properties of bituminous binders modified with WEO using thermochemical analysis. Modified bitumen and commercially prepared modified binder had a similar penetration test result but had greater softening point temperatures.

Qualities of WCO and the attributes of Rejuvenated Asphalt have been assessed. The findings of RV, DSR, and BBR tests had been carried out to assess the physical qualities of regenerated asphalt in this study. For analysis of the impact on asphalt chemical composition by WCO, SARA FTIR experiments were performed (Zhang et al., 2017).

The possibility of using waste cooking oil as a rejuvenating agent for aged bitumen was investigated (Zargar et al., 2012). The behaviour of WCO rejuvenated bitumen is investigated and compared to virgin bitumen after using the rolling thin film oven ageing technique. According to the findings, the old bitumen group 40/50 was rejuvenated to a condition roughly approximating the physical and rheological features of the original bitumen (80/100) using 3–4% WCO. However, there was a difference in the propensity to age between the WCO rejuvenated bitumen and the virgin bitumen during mixing, transport, and road laying. (Zahoor et al., 2021) worked on sustainable asphalt rejuvenation using waste cooking oil. The impact of WCO on the mechanical, rheological, chemical and macroscopic properties of the asphalt binder and the behaviour of asphalt pavements were studied. WCO added to the asphalt binder enhances the mixture's fatigue and thermal cracking, but at the cost of rutting resistance unless further polymeric modification is performed. In summary, Aged asphalts can perform as well as original asphalt with suitable content of WEO and WCO.

2.2.2 Waste tire rubber with Bitumen

Only a tiny fraction of trash tyres are now dumped on the ground in the modern world. New tyres, tyre-derived fuel, civil engineering applications and goods, moulded rubber products, agricultural uses, recreational and sports applications, and rubber-modified asphalt applications employ recycled tyre rubber. The advantages of employing asphalt mixtures modified using rubber are becoming typically recognised, and the addition of WTR in asphalt is anticipated to become more common (Lo Presti, 2013). If waste tires are not recycled and disposed of correctly, they pose severe health and environmental risks.

(Shu and Huang, 2014) worked on recent advances in using waste tire rubber in asphalt and portland cement concrete. The research concluded that because of the strong compatibility and interaction between rubber particles and asphalt binder, crumb rubber in asphalt paving mixes has long been proven beneficial, resulting in different enhanced qualities and performance of asphalt mixtures. Rubberised asphalt mixes have been compatible with two commonly utilised sustainability technologies in the asphalt paving industry: recovered asphalt pavement (RAP) and warm-mix asphalt (WMA).

Tire Rubber Waste Powder: Its Use and Impact on Bitumen Products was researched by (Mbereyaho et al., 2021). After confirming the standard quality of the utilised bitumen 60/70 grade, the research employed rubber waste powder as a partial replacement for conventional bitumen by 5%, 10%, 15%, and 20% of its weight. It analysed the characteristics of the bitumen product with suitable samples. It was observed that with a replacement rate of 5%, the best outcomes were generated.

Similarly, (Issa, 2016) evaluated the effect of adding Waste Tires Rubber (WRT) to Asphalt Mix. The physical properties of asphalt were studied. The virgin sample is made without rubber (4.5 per cent, 5 per cent, and 5.5 per cent bitumen). Other samples are made by mixing rubber with bitumen in a wet procedure at a rate of 5%, 10%, and 20% by bitumen weight. The results revealed that the qualities of the rubber–asphalt combination are superior to those of regular asphalt pavement. The usage of rubber tires on asphalt pavement is shown to be beneficial. The quantity of additional rubber that was found to be appropriate was 10% by bitumen weight.

(Mashaan and Karim, 2014) studied engineering properties of rubberised asphalt using WRT as a modifier. Varying laboratory experiments were used to identify and analyse the physical and rheological qualities of rubberised asphalt binder containing various percentages of crumb rubber modifier (0, 4, 8, 12, 16, and 20%). The effects of a 16 per cent crumb rubber modifier at 180°C blending temperature on altered binder engineering characteristics were found to be considerable.

A more recent was carried out using WRT in September 2020 by (Alfayez, Suleiman and Nehdi, 2020). Overall performance, economy, and sustainability of Asphalt pavement were improved by the researcher using recycled WRT. The asphalt binder’s temperature susceptibility was also found to have improved with WRT as the modifier. Similarly, its addition improve the resistance of pavement to rutting and deformation that is caused due to the high level of viscosity of the mixture. Moreover, it improves the binder's performance with respect to fatigue, load-bearing, and overall pavement sustainability. This can be achieved by reducing the use of energy and natural capital resulting in an overall decrease in the cost of repair and maintenance. Furthermore, the physical properties of the asphalt binder modified with WRT are greatly affected by parameters such as the form, volume, and particle size.

2.3 Binder physical properties

Bitumen characteristics are influenced by both the source of the oil and the mechanism of oil processing. The amount and ratio of asphaltenes and maltenes as fundamental components of bitumen become less relevant from the standpoint of the refinery; yet this might have a substantial influence on the future qualities of the bituminous binder (Holý and Remišová, 2019).

The properties of bitumen that matter the most in its bonding with aggregate in an asphalt mixture are adhesion, resistance to water, rigidity, viscosity, softening point, ductility, specific gravity, durability, and strength. Adhesion allows bitumen to bring together materials as it can bind depending on the nature of the materials. Its property to resist water allows it to act as a sealant. Hardness (measured by penetration test) makes it durable in different conditions. There are different grades of bitumen depending on hardness. Softening point and ductility are related to bitumen’s behaviour in different temperatures. Finally, durability and strength are the properties that determine the load-bearing capacity of the binder (Jamal, 2017).

2.4 Resilient modulus (M_R)

At a given temperature and load, resilient modulus (MR) is a ratio of applied stress to recoverable strain. Indirect tensile resilient modulus test is carried out using an IPC UTM-5P Universal Testing Machine following ASTM-D4123-82, Standard Test Method for Indirect Tension Test for Resilient Modulus of Bituminous Mixtures (Fernando Pacheco Torgal, 2019).

The stiffness of an asphalt mixture is a key metric to consider while designing pavement and evaluating its performance. The resilient modulus (MR) test (ASTM D7369) is performed to determine the stiffness of various types of asphalt mixes and specimen types (Munoz et al., 2015). The most important variable in mechanistic design techniques for asphalt structures is the resilient modulus. It is an assessment of the behaviour of asphalt to dynamic loads and strains. The test result is normally used to see if adding any additives to an asphalt mixture changed its stiffness qualities significantly. An example from (Fernando Pacheco Torgal, 2019) can be quoted here. Al_2O_3 with a concentration of 3%, 5%, and 7% was used as a modifier of asphalt. The results reveal that irrespective of the modifier type or content, resilient modulus drops as temperature rises. When compared to other modified asphalt specimens, the base asphalt cement has the lowest resilient modulus of 3528 mPa, while 5 per cent Al2O3 has the highest resilient modulus of 5082 mPa. To sum it up, the Resilient modulus shows that modified bitumen has improved the mixture's resistance to fatigue to mitigate pavement distress.

2.5 Moisture Susceptibility

The most significant performance factor determining the longevity of asphalt pavements is the moisture susceptibility of asphalt mixes, often known as stripping. Moisture-induced asphalt pavement degradation is a complex mechanism of distress that results in the loss of stiffness and structural integrity of the mixture, as well as the need for costly pavement maintenance (Diab, Singh and Pais, 2017). Due to cohesiveness in the asphalt binder membrane and adhesion between aggregate and asphalt binder, moisture sensitivity of asphalt mixes can cause significant damage to pavements (Nikookar et al., 2021).

There are numerous strategies for improving the moisture susceptibility of asphalt mixes, the most frequent of which is to use additives or modifiers (Mansourian and Gholamzadeh, 2016). An example can be given from (Ameri et al., 2016) research which investigated the impact of nano clay on rutting and moisture damages. The results were compared to neat and 4 per cent SBS-modified asphalt binder and mixes, as well as 4 per cent SBS-modified asphalt binder and mixes. Nano clay has a beneficial influence on rutting and moisture damage resistance of modified asphalt binder.

Similarly, (Nikookar et al., 2021) investigated moisture resistance of modified asphalt mixture using carbon nanofiber and modified aggregates with carbon nanotube. Generally, investigations proved that the addition of carbon nanotube as well as utilizing carbon nanofiber as an asphalt binder modifier had a positive impact on decreasing moisture sensitivity of asphalt mixtures.

Summary

There has been ample research on bitumen modification using waste materials in the past. The focus of these researchers has been to try different modifiers and see the impact of these modifications on the performance of asphalt. The performance of bitumen is dependent on the binder (bitumen). Bitumen is susceptible to failures under certain environmental and physical difficulties. Modifications are done to avoid temperature and load susceptibilities. These modifications are done through the addition of new materials or the replacement of bitumen with new materials.

Asphalt has different physical properties that are critical for structural longevity and integrity of the pavements. This physical property can be enhanced by using additives and modifiers. Examples of resilient modulus and moisture susceptibility are given in this chapter. Several modifiers can be added to the asphalt mixture to improve its performance.

WRT has been the most common modifier to replace bitumen in Hot Asphalt mixes. Past research on the modification of bitumen to improve its physical properties and performance of asphalt proves that it is a well-established model of research. It also shows that there is scope for using many other modifiers to achieve similar or even better results.

CHAPTER 3: METHODOLOGY

3.1 Introduction

The methodology adopted to perform different tests to achieve the required research objectives is discussed in this chapter. WRT, WCO and WEO have been used as binder modifiers and their effect on the physical, rheological and ageing characteristics of the binder are studied. Different test procedures were adopted to check the behaviour of virgin bitumen and modified bitumen with waste materials under similar conditions. NHA Class-B gradation was followed and the performance tests like the Indirect Tensile Strength test to find Tensile Strength Ratio (TSR), resilient modulus test and moisture damage test were conducted. While conducting this research work following methodology has been followed.

- Bitumen 60/70 grade was blinded with different percentages of WCO, WEO and WRT powder.
- Penetration, Ductility, Softening point, Flash and fire point and specific gravity were performed to determine the optimum percentage of waste material that can be used as a modifier with bitumen.
- Marshall Mix design parameters were used to determine optimum binder content (OBC).
- Performance properties of modified bitumen were determined after finding the optimum percentage of WRT, WEO and WCO that can be added successfully to bitumen. These rheological properties were then compared with the virgin bitumen 60/70.

3.2 Materials

The objective of this research is to replace the binder and improve its properties with waste materials so for this purpose selection of modified alternative binder material is a very crucial step. Materials are selected as per the availability and cost-efficiency of the material. Following materials were used for the preparation of samples for different experiments.

- Bitumen 60/70 PN-Grade
- Aggregates
- Waste cooking oil
- Waste rubber tire powder
- Waste engine oil

3.2.1 Bitumen

Bitumen used was 60/70 PN-Grade which was supplied by PARCO sales office Rawalpindi. The purpose of selecting the 60/70 grade is that it is mostly used in Pakistan and is appropriate for colder to Intermediate temperature regions.Bitumen without any modification in this research is termed virgin bitumen.

A manual mixing method was adopted in which bitumen was heated at 140°C and was stirred continuously for over 30 minutes. The stirring was done with a glass rod gently so that waste materials can be completely dissolved in bitumen.

3.2.2 Aggregates

For this research, the aggregates both fine and coarse were acquired from the Margalla quarry. The aggregate structure in the mix provides 95% approximately of the resistance to permanent deformation, with the asphalt binder accounting for the remaining 5%. To be able to endure the application of load regularly aggregates provide a strong stone skeleton.

3.2.3 Waste Cooking Oil

Waste cooking oil was obtained from two different restaurants in Islamabad and Rawalpindi. Literature review shows that as the acidic content of waste cooking oil increases its quality increases and it has a bad effect on bitumen's physical as well as rheological properties.

PH tests were performed on the two samples of waste cooking oil that were obtained from two different restaurants. Waste cooking oil having the lowest value was selected for further experimentation.

3.2.3.1 Waste cooking oil filtration

Waste cooking oil obtained from different restaurants contains suspended particles of different sizes. According to the literature review, a waste cooking oil that is free of impurities performs better than WCO which contains suspended particles and impurities. For this purpose, WCO were filtered using centrifugation and filter paper to eliminate any contaminants and suspended particles.

A universal centrifuge was used for the centrifugation of waste cooking oil. The main principle of this centrifuge is that a material from which impurities must be removed is placed in glass containers. After which a machine is started that rotates at varying speeds (rpm) depending on the size of impurities to be removed. Impurities are separated based on differences in densities due to the fast speed. High-density material settles to the bottom.

For this purpose, Waste cooking oil was poured into 4 glass tubes and placed in a centrifuge. Then the speed of the centrifuge was set to 4000 rpm. The temperature inside the centrifuge was set to 27^{o}C. The time limit for centrifugation was fixed at 30 minutes. Waste cooking oil was filtered in a centrifuge and then passed through filter paper to eliminate any remaining impurities.

Figure 3-1 Universal Centrifuge

Figure 3-2 Universal centrifuge (Bottles) and impurities left after filtration

Figure 3-3 Waste cooking oil after filtration

3.2.4 Waste Engine Oil

For this research, WEO was obtained from a local auto repair shop. Remains of several metals have been detected in this waste material in past studies. As a result, WEO was filtered to remove solid contaminants.

Figure 3-4 Waste engine oil after filtration through filter paper

3.2.5 Waste Tire Rubber Powder

In this research work, tire rubber powder use was obtained from the Swat tire industry in Peshawar, Pakistan, where tire rubber powder is produced in the recycling process at ambient temperature. The surface area of rubber tire powder is large and it has a spongy texture (Rubber tire powder was obtained by passing it through various sieves, with tire powder passing #100. The average size of the rubber tire powder particles was about 0.15mm.

Figure 3-5 Waste rubber tire in powder form

3.3 Mixing of waste materials with bitumen

A manual mixing method was adopted in which bitumen was heated to a temperature of 135C and stirred continuously for over 30 minutes. The stirring was done with a glass rod gently so that WRT, WCO and WEO can be completely dissolved in bitumen.

3.4 Material Testing

Physical and performance tests were carried out on Virgin Bitumen grade 60/70, aggregates and modified bitumen. Extensive physical testing was used to determine the optimum value of WCO, WRT, and WEO that can be used to replace bitumen. Different tests of aggregates were carried out to characterize their fundamental properties.

3.4.1 Physical testing of Bitumen

Physical test includes Penetration Test, ductility test, Softening point test, and specific gravity and viscosity test of the binder. These tests were conducted to determine the optimum percentage of bitumen that can be successfully replaced with WCO, WRT and WEO.

3.4.1.1 Penetration Test (AASHTO T-49 ASTM D-94)

To measure the consistency of bitumen at room temperature, a penetration test is used. This test is important for evaluating bitumen grade, which is then used to determine bitumen acceptability under various climatic circumstances. It measures the hardness or consistency of bituminous material. In this test, a standard loaded needle is vertically placed in a bitumen sample under standard conditions, and the penetration depth is measured in tenths of a millimetre. Penetration values are higher when the binder is softer. According to AASHTO T49, the temperature was maintained at 25°C, the load was 100 grams, and the test time was 5 seconds. After completing penetration tests on PARCO 60/70 specimens, three values were taken from each specimen.

Figure 3-6 Penetrometer

3.4.1.2 Ductility Test (ASTM D113-17)

A material's ability to withstand tensile stresses is known as Ductility. The ductility of bitumen is a very important property of bitumen and an essential factor in the performance of HMA. Ductility shows bitumen behaviour with changing temperature. In this test, the distance between the two ends of bituminous material in "cm" is measured by pulling them apart from each other at a speed of 5cm/min at a constant temperature of 25± 0.5°C till breaking. The distance was noted in cm at which the bitumen sample was broken. That noted distance represents the ductility value of the bitumen. In general, the material having ductility greater than 100 cm at this temperature is taken well for construction.

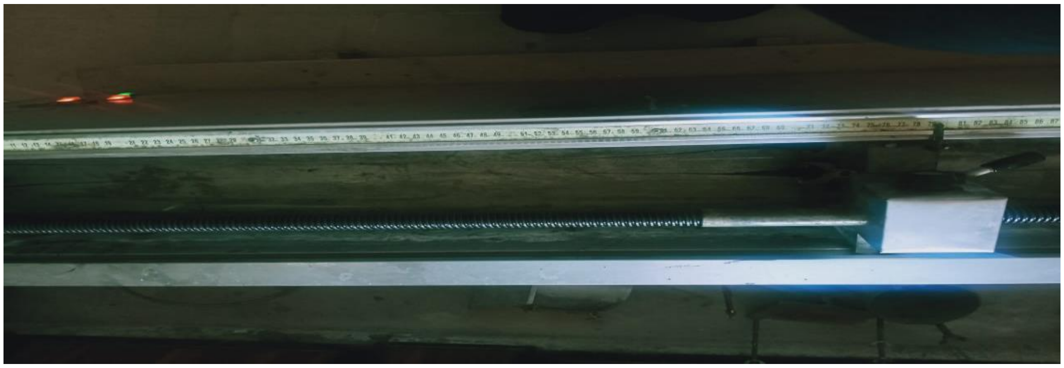

Figure 3-7 Ductility apparatus

Figure 3-8 Ductility test apparatus(sample preparation)

3.4.1.3 Softening Point Test (T53-06 ASTM D36-95)

Bitumen is a visco-elastic material, however as the temperature rises, it gets softer and its viscosity decreases. The temperature at which a bitumen sample can no longer support a typical 3.5-gram steel ball is known as the bitumen softening point. The softening point of bitumen is a mean temperature at which bitumen is soft enough to allow a steel ball to cover a distance of 25 mm. According to AASHTO-T-53, a ring and ball apparatus were used to evaluate the softening point of bitumen.

Figure 3-9 Softening Point test apparatus (ring and ball assembly)

Figure 3-10 Sample preparation for softening point test

3.4.1.4 Rotational Viscosity (AASHTOT-316 and ASTM D 4402)

This test is used to find out the viscosity at a high temperature which provides the basis for the selection of mixing and compaction temperature of bitumen. The basic principle of the rotational viscometer is that it senses the torque which is required to move the spindle immersed in a fluid with constant speed. The torque measured is proportional to dynamic viscosity. For that purpose, a sample of 10-11 grams by mass of bitumen was taken on the thermostat and run the test for 30 minutes at a temperature of 135°C and 165°C. The spindle rotates at a rate of 20 rotations per minute. Take three viscosity readings from the rotational viscosity meter's display once the sample has attained temperature. The viscosity will be calculated as the average of the three values.

Figure 3-11 Rotational Viscosity Test

3.4.1.5 Flash and Fire point

In this test, a dynamic method is used to measure the flash and fire point temperature. Bitumen is a flammable liquid at high temperatures and therefore, there is a risk of catching fire if care is not exercised during construction. It is used to define the critical temperature at and above which suitable precautions should be taken to eliminate fire hazards during its application. For this purpose, cleave open cup, heater and thermometer were used. Bitumen was heated at the rate of 5 ±1°C/minute. When the temperature reached near flash point or when sparking was started the test flame was applied to the surface of bitumen. Meanwhile, as the bitumen took fire that was the flash point. Noted the temperature and when it took fire for at least 5 seconds completely that was the fire point temperature. The mean value should not differ from the individual values by more than 30^{o}C for flash points and by 10^{o}C for fire points.

Figure 3-12 Flash and fire apparatus

3.4.1.6 Specific Gravity Bitumen

It is the ratio of a substance's mass to the mass of an equivalent volume of water at a certain temperature. The specific gravity of bitumen will be greater if it includes mineral contaminants. Thus, quantitative extraction of mineral impurities in bitumen is achievable. For that purpose, different masses of pycnometer were measured and specific gravity was calculated by the following formula:

Specific gravity = $\frac{(C-A)}{(B-A)-(D-C)}$

A = Mass of empty pycnometer

B = Mass of pycnometer filled with boiled distilled water

C = Mass of pycnometer with bitumen about three-fourth of its capacity.

D = Mass of pycnometer with bitumen plus freshly boiled distilled water.

Figure 3-13 Pycnometer for finding the specific gravity of the sample

3.4.2 Aggregate Testing

In the mix, aggregate is the central portion which resists permanent deformation and is expected to provide better resisting property to repetitive loads. To determine the fundamental features of aggregate, such as gradation, each stockpile was subjected to a specific gravity laboratory test. Tests conducted in the laboratory were;

- Los Angeles Abrasion
- Aggregate Crushing Value Test

- Aggregate Shape Test
- Impact Value Test
- Specific Gravity and Water Absorption Test of aggregates

All these tests mentioned above were conducted using three specimens and then the average was considered for further process.

3.4.2.1 Los Angeles Abrasion Test

This test is used to find the hardness of aggregates. Aggregates should be hard enough to withstand the wear generated by heavy traffic loads. The Los Angeles Abrasion Machine, a balance, set of sieves, and steel balls were used in this test. For this test, grading B was used. 2500 g of aggregate were retained on ½" and 3/8" sieves each, which is a total of 5000g (W1) of aggregate along with 11 steel balls or charges were placed in the machine. The machine was rotated for 500 revolutions at 30 to 33 revolutions per minute. The material was then sieved through a 1.7mm sieve. The weight of the sample passing through it (W2) was recorded. The abrasion value was calculated by the following formula;

Abrasion Value = W2/W1× 100.

Table 3.3 shows the tests performed on the aggregates

3.4.2.2 Aggregate Crushing Value Test

The aggregates must be strong enough to withstand traffic loads to achieve higher quality and strength of the pavement. A steel cylinder with open ends, a plunger, and a hole across it where a rod could be inserted to elevate it, cylindrical measure, balance, tamping rod, and a compressive testing machine are used for this test. Aggregates were passed through a set of sieves and material passed through a sieve sized ½” and retained on 3/8” were selected. The sample of aggregate was washed, oven-dried and weighed (W1) and then placed into a cylinder in layers of three. Every layer is then tamped twenty-five times. The aggregate sample was shifted into the steel cylinder with a base plate and the plunger was inserted; then placed in compressing testing machine and loads were applied. The crushed aggregate was then taken out and are then passed through a sieve sized 2.36 mm. The sieved aggregate is named W2 and the Crushing value is the ratio of W2 and W1.

3.4.2.3 Aggregate Shape Test

The shape of the particles determines not only the strength and workability of the binder mixture but also impacts the amount of work required for compaction, which is necessary to attain the desired density. As a result, the number of elongated and flat aggregate particles was determined using a shape test. According to ASTM D4791, flaky aggregates are defined as those with dimensions less than 0.6 of their mean sieve sizes, whereas elongated aggregates have lengths greater than 1.8 of their mean sieve sizes.

3.4.2.4 Impact Value Test

The resistance to breaking that aggregate provides is its impact value. An impact testing machine, tamping rod, and sieves of sizes 1/2", 3/8", and #8 were among the tools needed to determine the impact value (2.36mm.) Around 350g of aggregate passing through a 1/2" sieve and retaining on a 3/8" sieve was obtained and layered in three layers in the Impact Testing Machine mould, by tamping 25 times each Layer. The sample was placed in the machine's larger mould, and 15 blows were given at a height of 38 cm with a hammer weighing 13.5 to 14 kg. The aggregate was then extracted and sieved from sieve

#8. The impact value was calculated using the fraction of aggregates that passed through a 2.36 mm sieve.

3.4.2.5 Specific Gravity and Water Absorption Test of Aggregates

3.4.2.5.1 For Coarse Aggregate

The specific gravity and water absorption of coarse aggregate were measured according to the procedure and techniques mentioned in ASTM C 127 standard. In this test, three types of weights were found i.e., submerged weight in water, the weight of aggregate in saturated surface dry condition and oven-dry weight of the aggregate.

3.4.2.5.2 For Fine Aggregate

Specific gravity and water absorption of coarse aggregate were measured according to the ASTM C 128 standard. The specific gravity of fine aggregate was measured using a pycnometer. Different four types of weight were measured. The results were obtained after the testing of materials.

3.4.3 Ageing tests of Bitumen

3.4.3.1 Rolling thin film oven (AASHTO T 240: ASTM D 2872)

To assess the quality of bitumen, evaluation of rheological properties after short-term ageing of bitumen is very important. Short-term ageing was stimulated using this test in the laboratory. Bitumen in RTFO was aged by heating and blowing hot air at 163ºC for 85 minutes. The short-term ageing in bitumen is the loss of volatility when it is heated at the asphalt plant and subsequently laid at the site.

Figure 3-14 Rolling thin film oven (bottles)

3.4.3.2 Pressure ageing vessel (AASHTO R 28: ASTM d6521)

This test was used to induce the long-term ageing of asphalt i.e. 7 to 10 years by applying heat and pressure for 20 hours in the laboratory.

The following apparatus was used

- Sample Pan/trays
- PAV
- Vacuum oven

3.4.4 Asphalt Mix Preparation

In this research, three different categories of asphalt mixtures were prepared; one was a mixture of asphalt, the second contained an optimum percentage of waste engine oil with waste tire rubber in bitumen and the third contained an optimum percentage of waste cooking oil with waste tire rubber in bitumen. These different mixtures were prepared with OBC which was calculated with the help of Marshall Mix Design. It is the core premise for designing asphalt mixtures because the pavement produced with the best blend of aggregate and binder would have better performance and a long life span. Because the aggregate structure is vital in preventing deformation, mix design should include a mix that can resist densification under traffic load while causing minimal changes in air voids after construction. The asphalt mixture should have strong shear and tensile strength, as well as flexibility and moisture resistance. The shear strength of a mixture can be increased by using a good quality aggregate with the proper gradation. One of the most essential considerations when choosing a mixed design is the presence of air voids. Adequate air voids should be included in the mix to ensure that the pavement is durable and does not rut owing to a lack of them. Total air voids depend on VMA, aggregate structure, fines content compaction, binder content and nominal maximum aggregate size.

Different processes have been established to identify the appropriate percentages of components for the mix in the laboratory, but for asphalt mixture design, the Marshall Method is most commonly recommended and used. Bruce G. Marshall of the Mississippi Department of Highways created it in 1939. ASTM D 6926 is the standard specification for this test. It should only be used in asphalt paving mixtures with a maximum aggregate size of 1 inch (25 mm). If the aggregate size of the mix is greater than 1 inch, a modified procedure is utilized.

3.4.4.1 Gradation selection

According to the general specification of NHA (1998), NHA class B gradation for asphalt concrete wearing coarse was used in this study. The maximum aggregate size was 19 mm. Mid-curve gradation was selected for virgin material shown in Table 3-1

Table 3-1 Aggregates gradation according to NHA class B specifications

Sieve Number	Sieve Sizes (mm)	NHA Class B Specifications	Mid Curve Selection	% Retained
3/4"	19	100	100.00	0.00
1/2"	12.5	75---90	82.50	17.50
3/8"	9.5	60---80	70.00	12.50
#4	4.75	40---60	50.00	20.00
#8	2.38	20---40	30.00	20.00
#16	1.18	5---15	10.00	20.00
#200	0.075	3---8	5.50	4.50
Pan	Pan	-------	0.00	5.50

Figure 3-15 Sample aggregates for asphalt

3.4.4.2 Bitumen and Aggregate Preparation

First of all, the aggregates were sieved through a set of sieves mentioned in the gradation chart of NHA class B grading and placed in separate containers. After sieve analysis, aggregates were dried to constant weights at 105°C to 110°C. Approximately, 1200g of material is required for a single Marshall sample. The mould has a diameter of 4 inches (101.6 mm) and a height of 2.5 inches (63.5 mm). The amount of binder required to prepare the mix specimen was calculated as a portion of the weight of the total asphalt mix and found using Equation

$$T=A+B$$

$$B=X/100(T)$$

Where:

T = Total Mass of Mixture

A = Total Mass of Aggregate in the mixture

B = Total Mass of Binder in the Mixture

X = Percentage of Bitumen

For the modified bitumen sample, the amount of replaced bitumen was calculated and the mixture was prepared before mixing it with aggregates.

3.4.4.3 Aggregate and binder mixing

A mechanical or hand mixer should be used to properly mix bitumen and aggregate, according to ASTM D 6926. The heated aggregate and asphalt were placed into the mixer after being removed from the oven. The temperature at which the binder is mixed should be between 0.22 and 0.45 Pa.sec, as specified by the Superpave mix design (SP-2). As a result, a temperature range of 160°C to 165°C was chosen, which corresponds to the temperature for the preparation of bituminous mixtures in the NHA Specifications (Pakistan).

Figure 3-16 Bitumen preparation before mix design

3.4.4.4 Preparation of mixes for Marshall Mix Design

The ASTM D 6926 standard recommends that the mixtures be conditioned for two hours before compaction. As a result, after mixing, the bituminous mix was transferred to a metal pan and placed in the oven at a temperature of 135°C for compaction. The mix was compacted at 135°C using an Automatic Marshall Compactor after two hours of conditioning. The mould assembly includes the cylinder, base plate, and extension collar.

The cylinder has a 3-inch height and a 4-inch interior diameter. Both ends of the mould can be swapped out for the collar. A piece of filter paper was placed in the mould assembly after it was completely cleaned and exposed to heating between 95°C and 150°C. The mix was then placed in the mould with the help of a scoop and spatula and after filling in three layers a piece of filter paper was placed over it. The mould assembly was then placed in the compaction pedestal's mould holder. On the mould, the hammer was properly positioned. For this study, the design requirements for a dense-graded wearing course were EAL > 106 or a heavily loaded pavement. To imitate heavy traffic, 75 blows were applied mechanically to the sample for compaction purposes. The specimen was inverted, the mould was rebuilt, and the same number of blows was applied to the other face of the specimen.

After compaction of both the sides, the assembly was removed, and the sample was allowed to cool to a suitable temperature so that it can be removed. The specimen was then extracted from the mould using an extraction jack. These extracted specimens were placed on a flat surface and permitted to cool down to an ambient temperature of the room.

Figure 3-17 Marshal Samples for OBC

3.4.4.5 Volumetric Analysis and optimum asphalt content

3.5% binder by weight is used as starting point for the calculation of optimum binder content (OBC). Five percentages 3.5%, 4%, 4.5%, 5% and 5.5% by weight binder (as specified by JMF) is used for all different mixture combinations. The volumetric properties, stability and flow correspond to the virgin mix in the table.

Table 3-2 Volumetric properties of the mix

AC	Gmb	Gmm	Unit weight	Va	VMA	VFA	Stability (KN)	Flow (mm)
3.50%	2.34	2.47	2.32	5.88	14.53	59.52	11.96	2.18
4.00%	2.35	2.47	2.35	4.53	13.87	67.42	12.66	2.62
4.50%	2.37	2.47	2.37	3.75	13.67	72.58	13.35	3.13
5.00%	2.38	2.46	2.38	3.14	13.93	77.46	13.36	3.65
5.50%	2.37	2.43	2.37	2.56	14.63	82.48	13.11	4.38

For the determination of optimum asphalt contents of mix having 0% waste material, the graphs between asphalt contents and volumetric properties, stability and flow were plotted according to the MS-2 manual as shown in Figure while the job mix formula of this mix is presented in Table 3-3.

Table 3-3 Job mix formula for PARCO 60/70

Parameters	Measured value	Criteria	Remarks
Optimum Asphalt Content	4.3	NA	
VMA %	13.77	13 (min)	Pass
VFA %	70.1	65-75	Pass
Stability (KN)	13.10	8.006 (min)	Pass
Flow (mm)	3.1	2.0-3.5	Pass

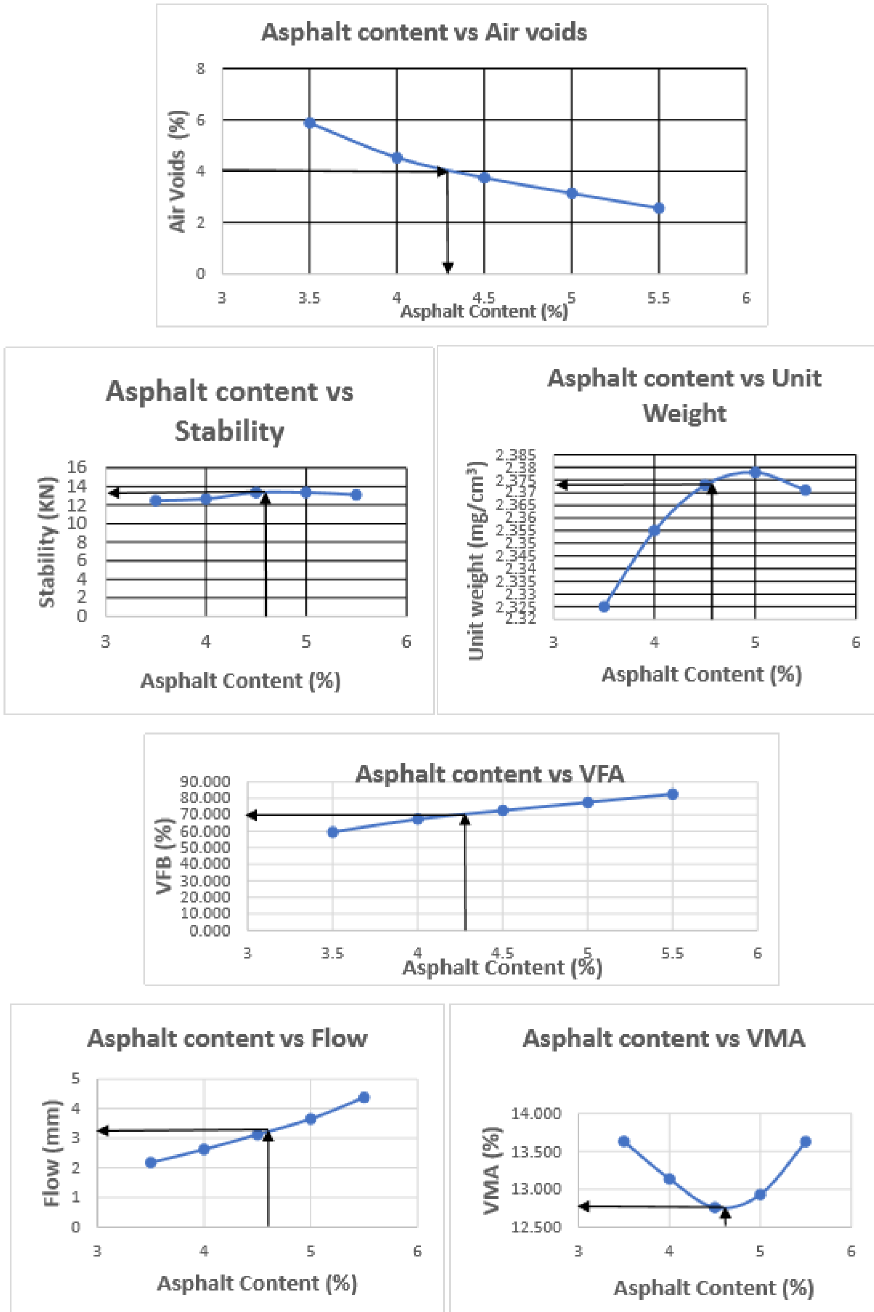

Figure 3-18 Graphs of Volumetric Properties of Mix having 0% waste material

3.4.5 Performance Testing

Following performance tests were performance

3.4.5.1 Indirect Tensile Strength Test and Moisture Susceptibility Test

When the pavement is continually exposed to cyclic loading, the tensile stresses and strains at the bottom of the asphaltic layer are produced. The tensile strength qualities of bitumen mixes determine their resistance to fatigue cracking. The stresses produced by traffic loads are determined by the pavement's overall stiffness characteristics. Tensile strength of bitumen mix is an indicator of stiffness and adhesion properties against rutting, fatigue and cracking due to temperature. For that purpose, samples are prepared on optimum bitumen content with the optimum amount of rubber and oil decided as per measured from different physical testing of bitumen. In the laboratory, the indirect tensile strength of mixtures was calculated by compressive loading in a vertical plane along its diameter. The loading setup develops homogeneous tensile stresses in the direction of applied load, causing the sample to break by splitting along the vertical diameter, as illustrated in the figure. The moisture susceptibility test was conducted as per ASTM D 6931-07. Three specimens per mix were tested unconditioned. These unconditioned samples were placed in a UTM at 25±1°C one hour before testing. Another set of three samples per mix was tested and conditioned. Conditioning of samples was done according to ALDOT-361 i.e., samples were placed in the water bath at 60±1°C (140±1.8°F) for 24 hours. Both unconditioned and conditioned samples were loaded on their diametric plane at a constant rate of 50 mm/minute. For each sample, the tensile strength was then calculated using the formula,

$$ITST = (2 \times P) / \pi \times D \times H$$

Where,

P = Failure or Peak load (N)

H = height of sample (mm)

D = Diameter of sample (mm)

The tensile strength ratios were then found as the ratio of average conditioned tensile strength to the average unconditioned tensile strength. The acceptable value for tensile strength ratio is 80%

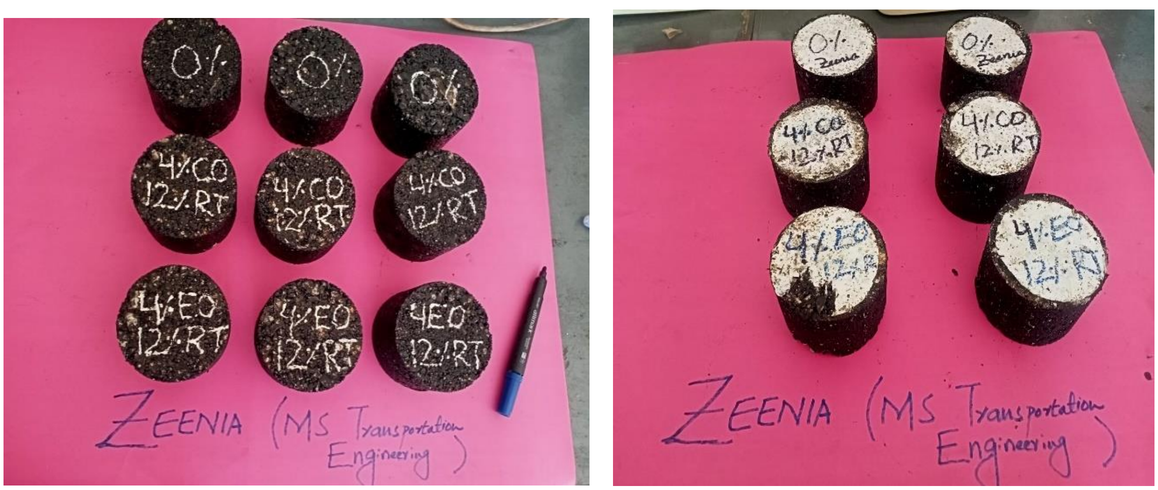

Figure 3-19 Sample for IDT and moisture susceptibility test

Figure 3-20 Sample for IDT and moisture susceptibility test in the oven for 24hrs (conditioned sample)

Figure 3-21 Sample for oven-dry and sample testing in UTM

3.4.5.2 Resilient Modulus Test

It is a fundamental property of the material that is used to define unbound bituminous materials and the degree to which the bituminous material recovers after disturbance. It is determined using laboratory tests that involve assessing the stiffness properties of cylindrical samples using the indirect tensile strength test technique, with loading levels depending on indirect tensile strength. The sample was placed in the universal testing machine (UTM-25), and an alignment mechanism was utilized to maintain the linear variable differential transducers (LVDTS) in place horizontally and vertically. As illustrated in figure 4.11, the UTM-25 is a closed-loop system with a chamber in which conditioning is done for evaluating bitumen specimens at various temperatures. In this research, the resilient modulus test was conducted at 25°C. The sample was subjected to a cyclic load of sinusoidal shape and data acquisition was taken by five load pulses. The response of the sample was determined by linear variable differential transducers.

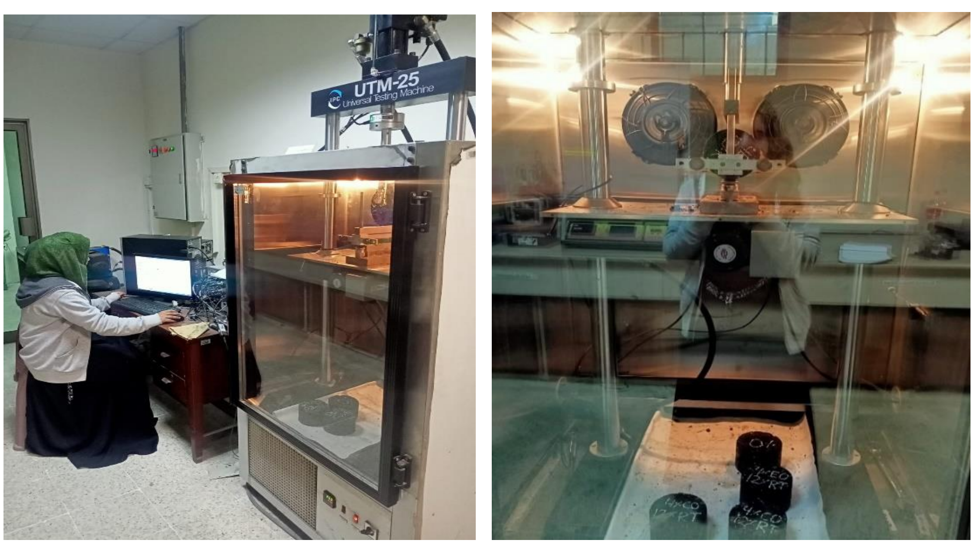

Figure 3-22 sample testing for Mr value in UTM

Summary

In this chapter, the methodology adopted to obtain the desired objectives is discussed. According to the climatic conditions of Pakistan, Virgin bitumen 60/70 was selected. In most of the regions of Pakistan, a bitumen of Penetration Grade 60/70 is used. Waste cooking oil having Less Ph value was obtained from a well-known restaurant in Islamabad. Waste engine oil was collected from a local auto repair shop. Waste Tire rubber powder was collected from Peshawar and further, it was sieved from the #100 sized sieve to get the finest form of it. Bitumen is blended with different percentages of WCO/WEO with WRT powder. The percentage of WCO and WRT powder blended with bitumen in the different trials were 2, 4, 6, 8(WCO) and 4, 8, 12, 16 (WRT) respectively. Bitumen is mixed first with tire rubber powder and then heated at a temperature of 160. After that waste cooking oil was added to the heated mixture of bitumen and rubber powder. The overall mixture was again heated at a temperature of 110 for 15 minutes. The same process was repeated with waste engine oil and waste tire rubber powder mixture with bitumen. The optimum percentage of WCO/WEO and WRT replacing bitumen were selected based on physical tests which include penetration point, softening test and viscosity test. Marshall mix design was performed to find out the optimum value of asphalt to be used. The selected optimum blend with WCO/WEO and WRT is tested to find out the tensile strength and modulus of resilience of asphalt. The aim is to determine the replacement of bitumen with WCO/WEO and WRT whether will act like normal bitumen or not.

CHAPTER 4: RESULTS AND ANALYSIS

4.1 General

This study focuses on the use of WCO, WEO and WRT as bitumen replacement. Bitumen is blended with different percentages of WCO, WEO and WRT. An optimum blend was selected, and different performance tests were performed on that optimum blend. The aim is to determine the quantity of Bitumen that can be replaced with WCO, WEO and WRT without adversely affecting virgin bitumen properties.

4.2 Physical Test Results

Physical tests were performed on virgin bitumen and bitumen mixed with different percentages of WRT, WCO and WEO. Physical tests include penetration test, softening point test, ductility test, flash and fire test, specific gravity test and viscosity test. These tests were conducted to find the optimum blended bitumen percentage.

4.2.1 Penetration Test Results

A penetration test was used to determine the optimum percentage of bitumen that can be replaced with different percentages of WRT, WCO and WEO. The optimum percentages of WRT, WCO and WEO were determined by carrying out a series of penetration tests on 54 samples. The result indicates that with the addition of 4 per cent of waste cooking oil increases the value of penetration of 60/70 Grade bitumen to about 160/180 penetration value. Same with the addition of WEO penetration value 60/70 grade of bitumen increases but lower than with the addition of WCO. Results show that with increasing the quantity of vegetable oil and waste engine oil in bitumen the value of penetration increases. (Khan et al., 2019) also had a similar finding in his research.

It is because with the addition of waste cooking oil asphalt consistency changes asphalt becomes soft. The addition of tire rubber powder makes the sample stiffer as the percentage of tire rubber powder increases the penetration value decreases.

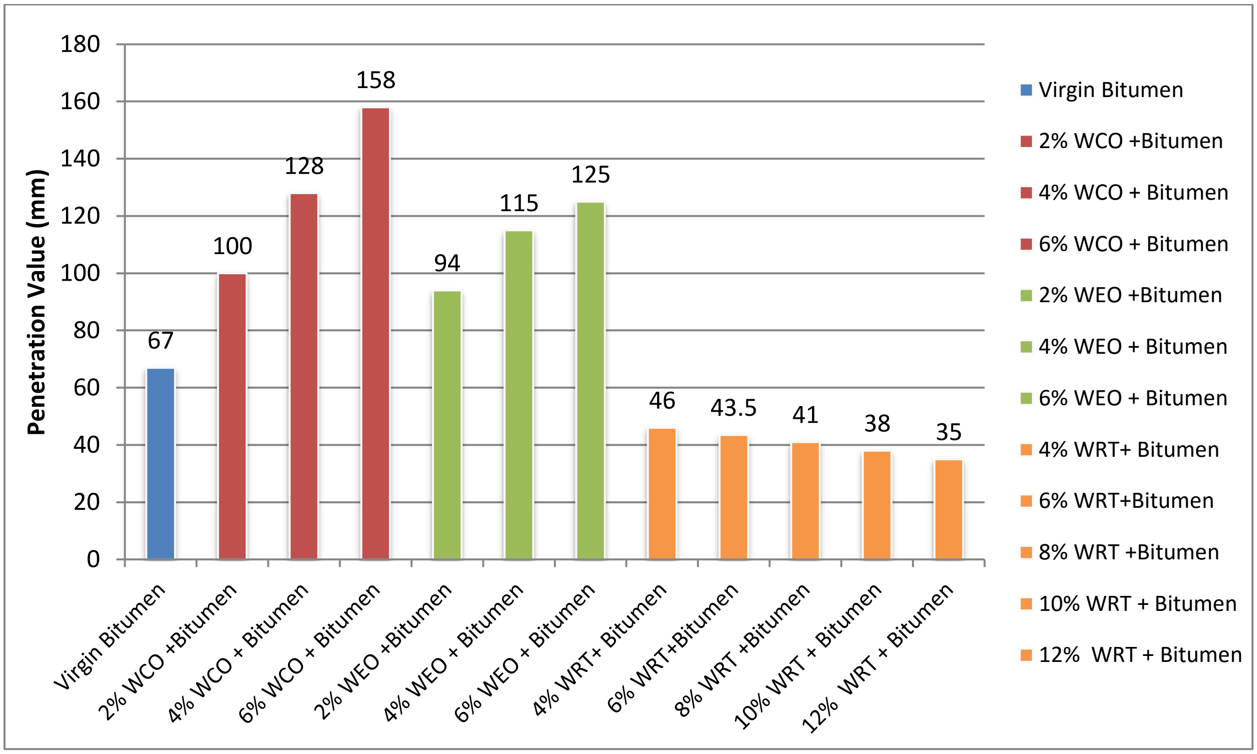

Figure 4-1 Graph showing the result of penetration value with different percentages of waste (WCO, WEO and WRT) in bitumen

However, the below figure shows that if we take the 4% optimum value of waste engine oil and vegetable oil separately with varying the quantity of only rubber in bitumen, the penetration value will increase. It shows that using 4% optimum vale of oils with 12% of rubber tire has better results than other combinations near virgin bitumen. Following are the results of all trials performed to obtain penetration Grade in the range of 80-100.

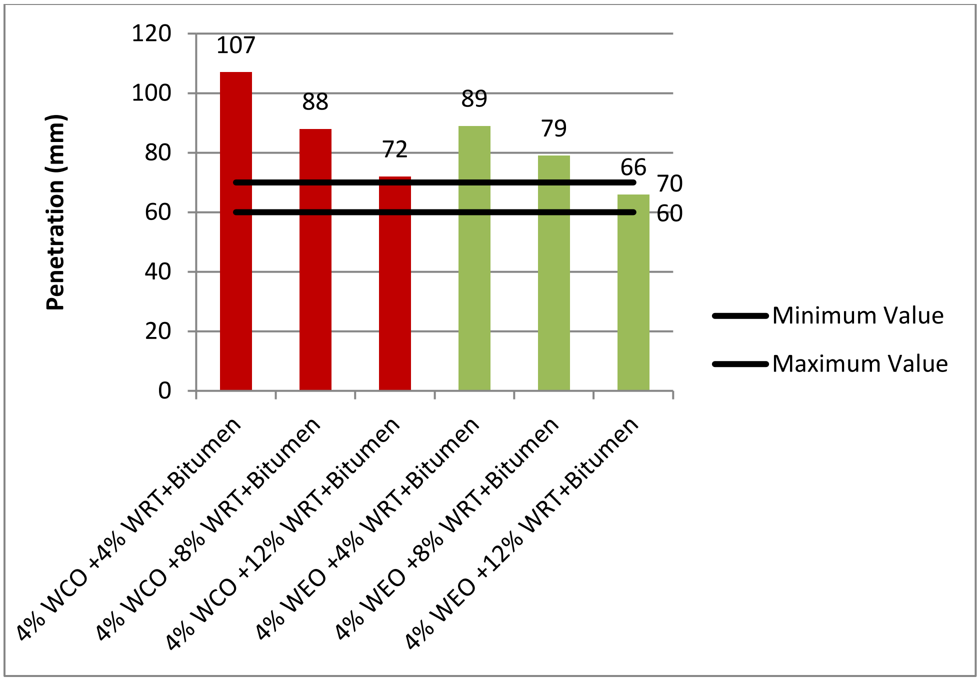

Figure 4-2 Graph showing the result of penetration value with different percentages of waste (WCO and WEO in combination with WRT) in bitumen

The results are very similar to the findings of (Yigezu Tefera, 2018) who worked on crumb rubber modified bitumen with Crumb rubber. Research carried out by (Khan et al., 2019) on Modified Bitumen with Replaced Percentage of Waste Cooking Oil & Tire Rubber shows similar results.

4.2.2 Softening Point Test Results

It is the measure of the temperature susceptibility of the bitumen. Usually, the greater the penetration grade of bitumen less will be the softening point. Similarly, the lesser the penetration grade value of bitumen more will be the softening point.

Results show that with increasing the quantity of vegetable oil and waste engine oil in bitumen the value of softening point decreases. While with the addition of rubber tire in bitumen increases the value of penetration. (Khan et al., 2019) also found out that increase in the percentage of WCO (hydro-carbon) in bitumen results in a dropping in softening point value. This is because Bitumen, WCO and WEO are all Hydrocarbons.

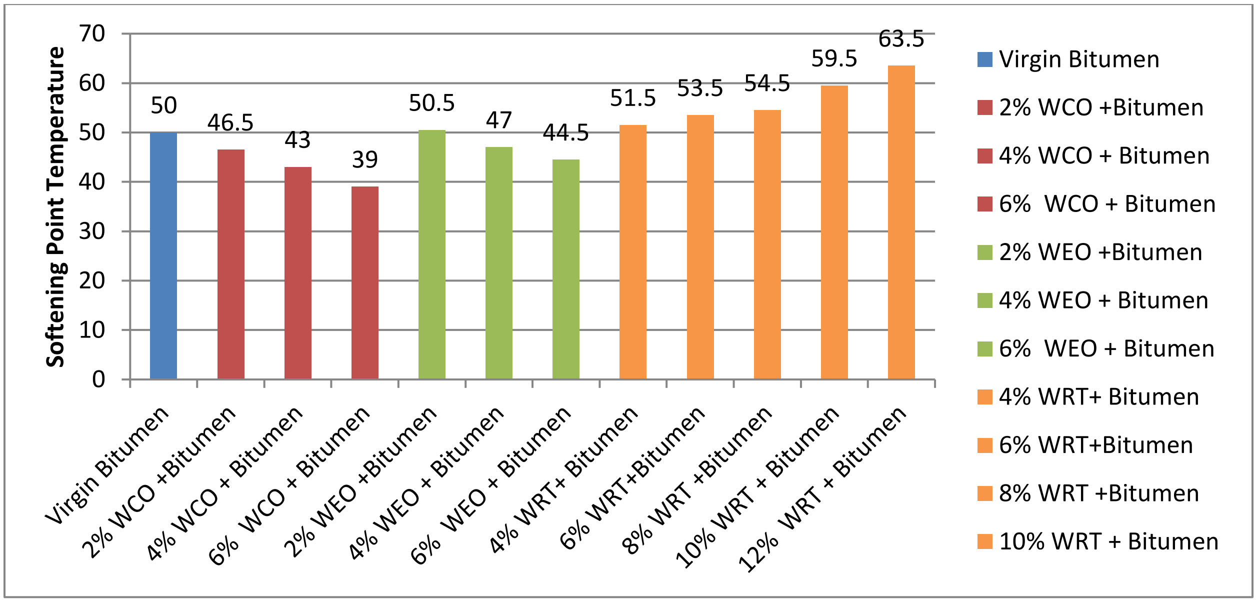

Figure 4-3 Graph showing the result of softening point temperature value with different percentages of waste (WCO, WEO and WRT) in bitumen

While it shows that using 4% optimum vale of oils with 12% of rubber tire has better results than other combinations.

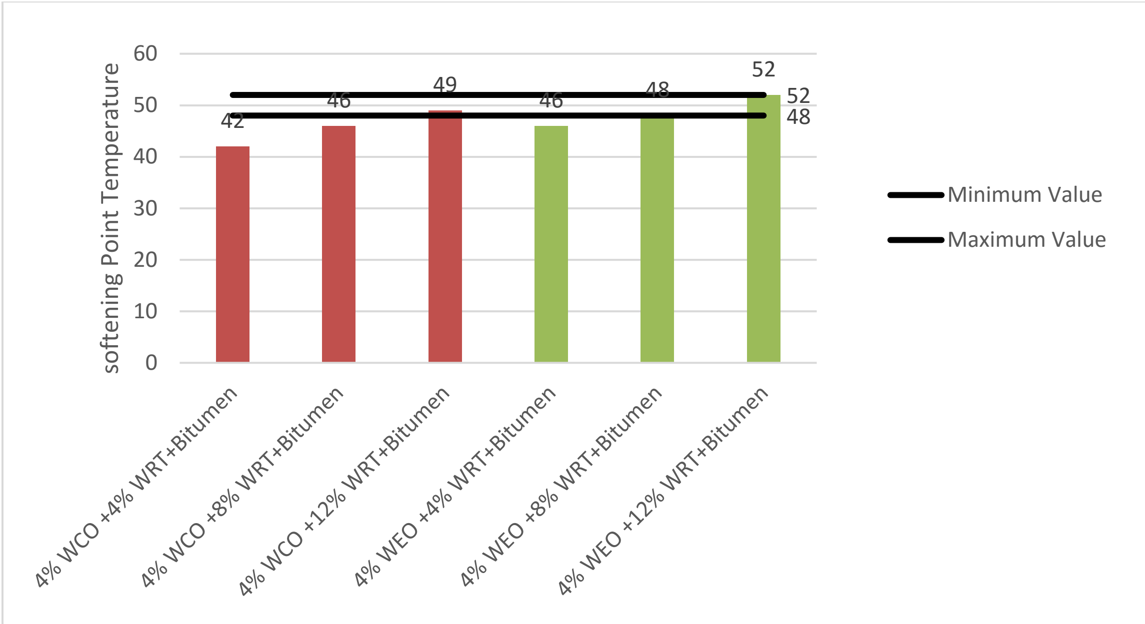

Figure 4-4 Graph showing the result of softening point temperature value with different percentages of waste (WCO and WEO in combination with WRT) in bitumen

Softening point values of WRT modified bitumen equates to the findings of (Yigezu Tefera, 2018) in his research.

4.2.3 Ductility Test Results

With the addition of oil in bitumen ductility value remains above 100 cm, meeting the requirement of ductile behaviour of bitumen. However, with the addition of rubber in it, the sample breaks before 75cm (minimum requirement for ductility).

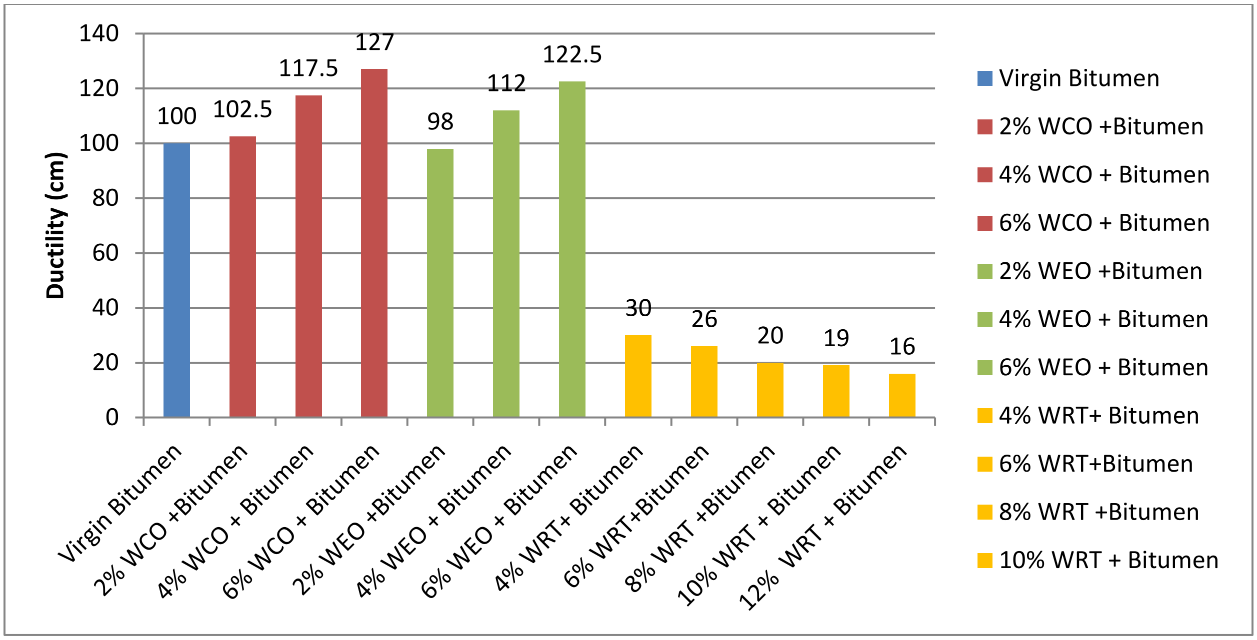

Figure 4-5 Graph showing the result of ductility value with different percentages of waste (WCO, WEO and WRT) in bitumen

Tire rubber powder is a stiff material which can decrease the bitumen softness and can provide extra stiffness to bitumen. A high percentage of tire rubber in bitumen is not recommended as it absorbs oily from bitumen which will lead to excessive decrease ductility. (Badri, Alkaissi and Sutanto, 2021) also explained in his research that crumb rubber reduces the ductility of the binder significantly.

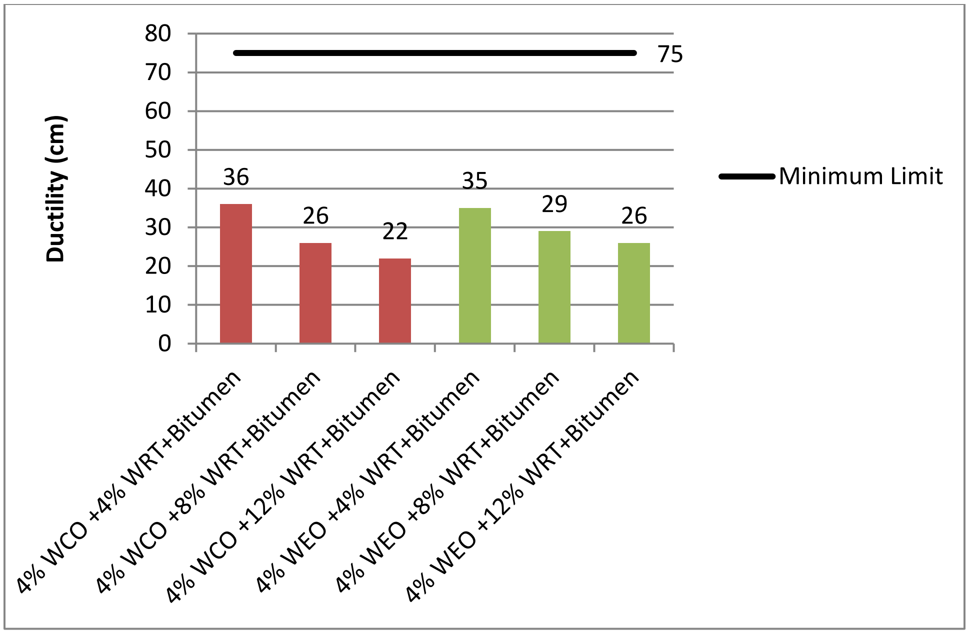

Figure 4-6 Graph showing the result of ductility value with different percentages of waste (WCO and WEO in combination with WRT) in bitumen

4.2.4 Flash and Fire Test Result

A Flash and fire test was conducted on an optimum sample having 4% of waste oil and 12% of waste rubber tire. The values obtained from the test show that by adding waste material to bitumen, it remains within the permissible limits required for the bitumen application. The table shows the values of flash and fire points of bitumen.

Table 4-1 Table showing results of Flash and Fire point of bitumen with waste material

Sample	Flash Point	Fire Point
Virgin Bitumen	351	357
4% WCO +8% WRT+Bitumen	350	357
4% WEO +8% WRT+Bitumen	344	364

4.2.5 Viscosity Test Results

4.2.5.1 Viscosity (Unaged)

With the addition of WCO and WEO, the viscosity of bitumen decreases substantially. Because oil contains acid which is lighter than other compounds in bitumen. With the increase in temperature, the viscosity of waste cooking oil tends to decrease.

While with the addition of WRT in the mix, the rubber tire increases the viscosity of the bitumen sample from that containing oil. Fist value represents the viscosity of bitumen at 135^{o}C while the second value represents that viscosity at 165^{0}C.

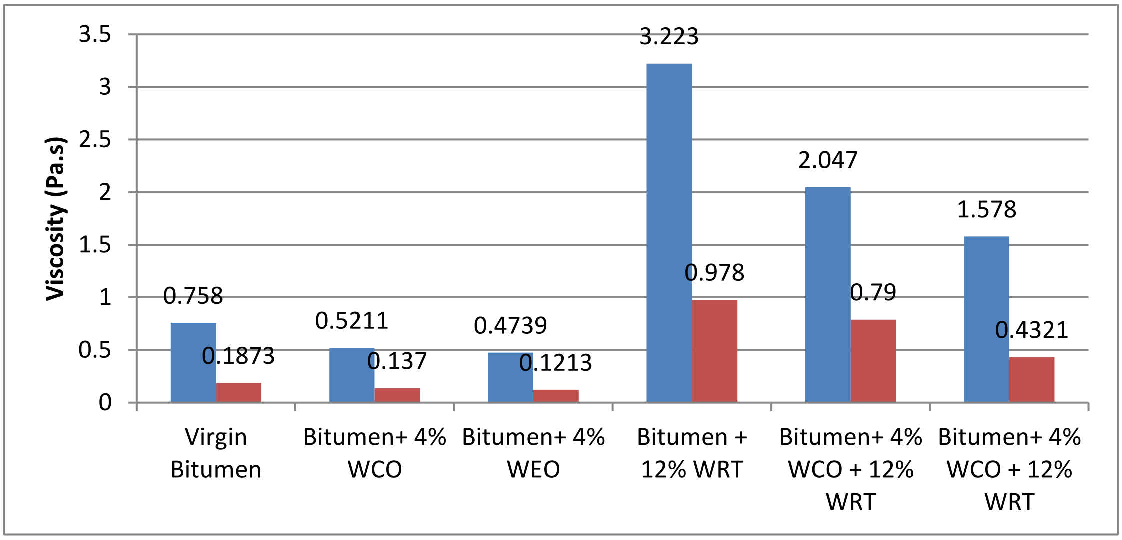

Figure 4-7 Graph showing the value of viscosity (unaged) with different percentages of waste (WCO and WEO in combination with WRT)

4.2.5.2 Viscosity (RTFO aged)

While after RTFO (short-term ageing) it seems that the viscosity of all the mixes increases from the previous one.

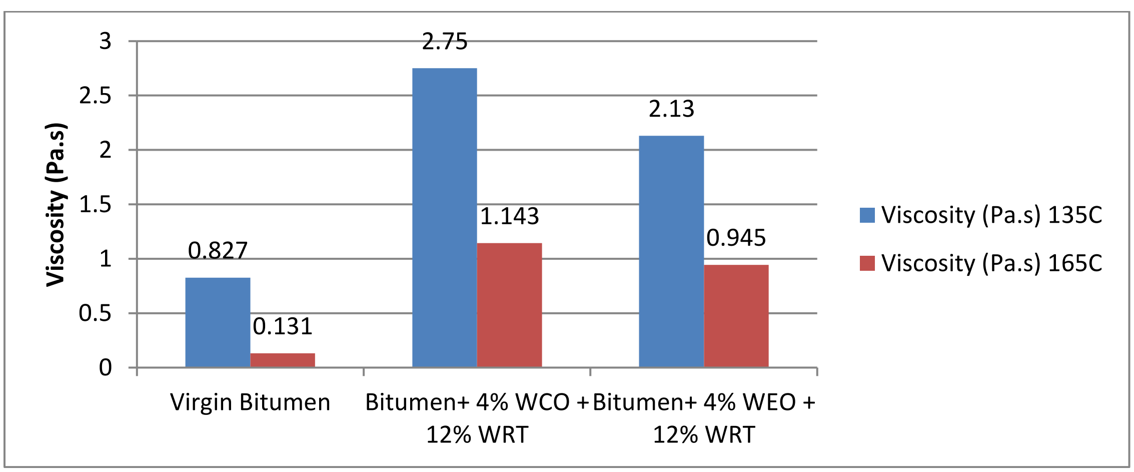

Figure 4-8 Graph showing the value of viscosity (aged) with different percentages of waste (WCO and WEO in combination with WRT)

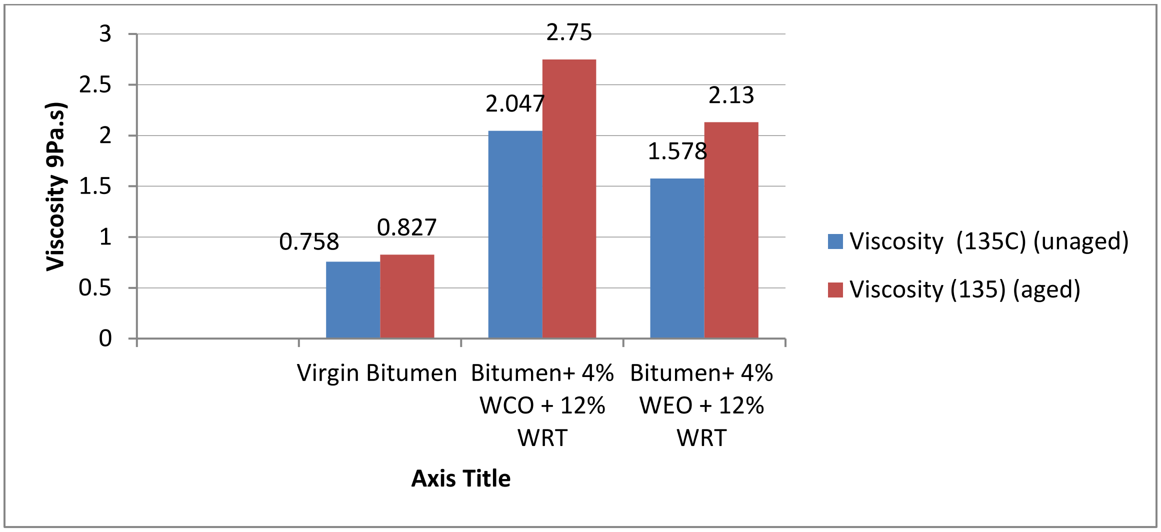

Figure 4-9 Graph showing the value of viscosity (unaged and aged) at 135C with different percentages of waste (WCO and WEO in combination with WRT)

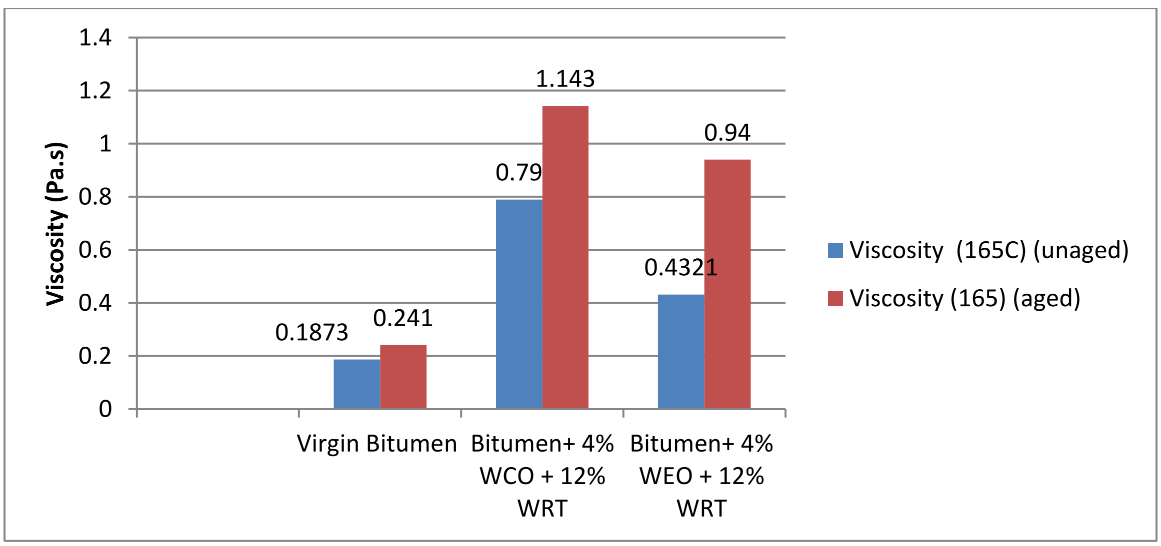

Figure 4-10 Graph showing the value of viscosity (unaged and aged) at 165C with different percentages of waste (WCO and WEO in combination with WRT)

4.3 Results of Performance Testing

4.3.1 Indirect Tensile Strength Test (Moisture Susceptibility Test)

Moisture susceptibility testing can be performed to determine if HMA mixes are on verge of moisture damage. The results of the moisture susceptibility test may be used to predict long-term stripping and evaluate the effectiveness of anti-stripping additives added to the asphalt binder, aggregate, or HMA mixture to prevent stripping. This test was conducted at 25C temperature.

Table 4-2 TSR test details and results

Sample	Temperature	Thickness (mm)	Diameter (mm)	Peak Load UC (N)	Peak Load C (N)	Tensile Strength UC (Pa)	Tensile Strength C(Pa)	Tensile Strength UC (KPa)	Tensile Strength C(KPa)	TSR %
0%	25	64	101	6074	5272	0.598	0.519	597.969	518.97	86.79
4%WCO+12%WRT	25	64	101	4695	4294	0.4626	0.4227	462.631	422.73	91.38
4%WEO+12%WRT	25	64	101	5764	4689	0.568	0.4616	567.967	461.62	81.28

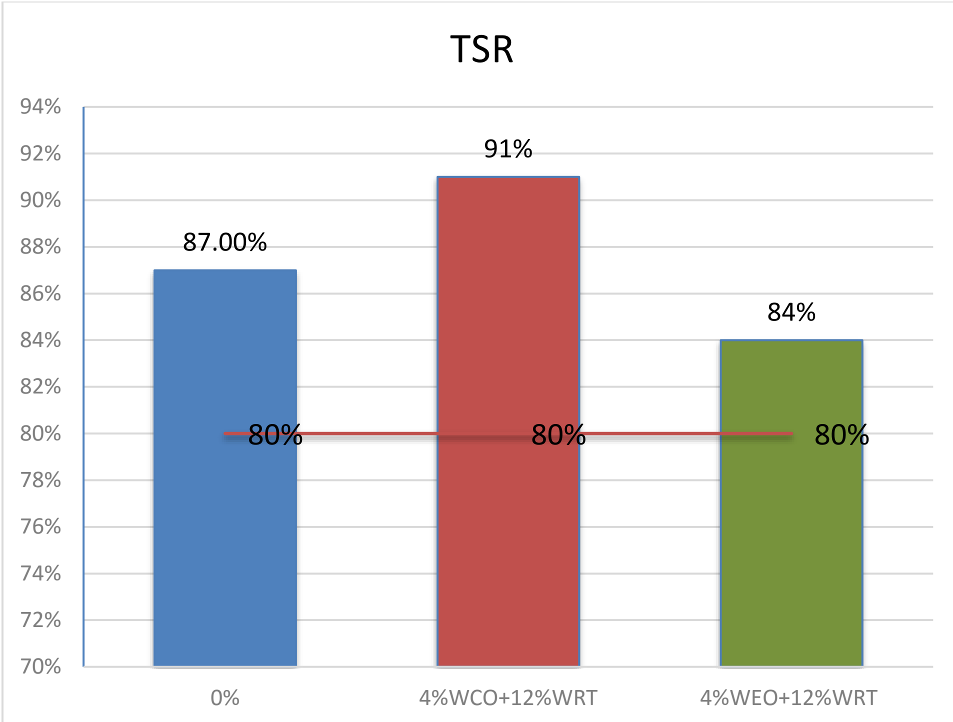

Figure 4-11 Effect of waste material on tensile strength ratio

(Abdul Hassan et al., 2019) explains in his research that Rubber-bitumen interaction stiffens the binder and the ability of fine rubber particles to distribute well within the mix during compaction, thus producing a mixture with greater stability.

4.3.2 Resilient Modulus Test Results

It is a fundamental attribute of material that is used to characterize unbound bituminous materials, and it is the degree to which the bituminous material recovers after disturbance. It is determined using laboratory tests that involve assessing the stiffness properties of cylindrical samples using the indirect tensile strength test technique, with loading levels depending on indirect tensile strength. The sample is placed in the universal testing machine (UTM-25), and an alignment mechanism is utilized to keep the linear variable differential transducers (LVDTS) in place horizontally and vertically. The UTM-25 is a closed-loop system with a chamber in which bitumen specimens are conditioned for testing at various temperatures. are conditioned for testing at various temperatures.

The resilient modulus test is carried out at a temperature of 25°C in this study. The specimen is exposed to a sinusoidal cyclic load, and data is collected using five load pulses, with the response of the specimen calculated using linear variable differential transducers. ((Abdul Hassan et al., 2019) found out that crumb rubber at 25 degrees Celsius Mr value tends to decrease a bit with WRT as an additive in asphalt mixture which is evident in our research with 12% WRT, Mr value has reduced significantly.

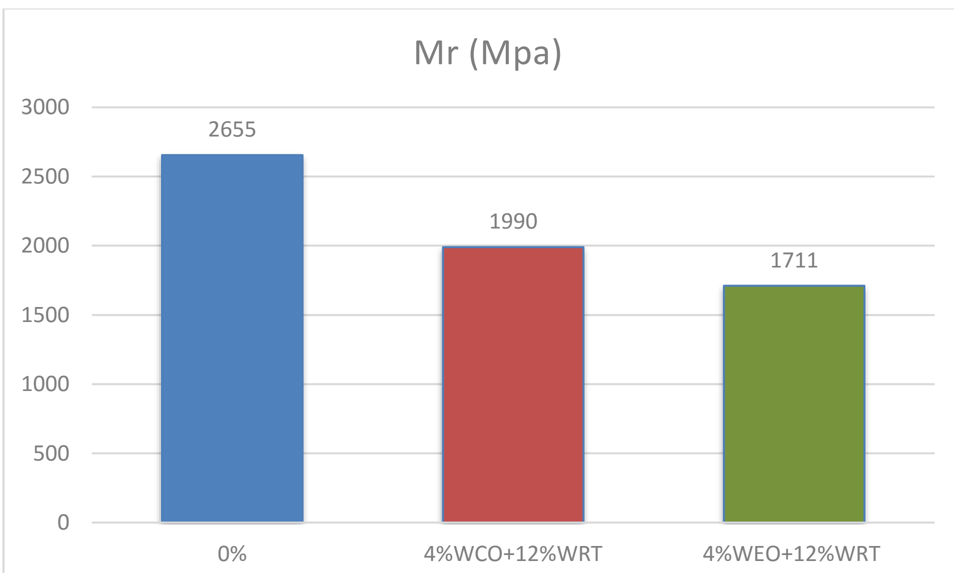

Figure 4-12 Effect of waste material on Mr value

4.3.3 Cost Analysis

4.3.3.1 Virgin Bitumen

Assume 1km long, 3.6m wide and 50mm thickness of road segment.

Volume of mixture = 1000m x 3.6m x .050m = 180m³

Density assumed = 2360 kg/m³

Total weight of mixture for 1km road segment = 424.8 tons

OBC = 4.3%

Weight of bitumen required = 18.27 tons

For production of 100 tons of HMA:

Cost evaluation

OBC = 4.3%

Weight of binder in mixture = 4.3 tones

Weight of aggregate in mixture = 95.7 tons

Cost of Binder @PKR190000/Ton = 190000*4.3 = 8,17,000 PKR

Cost of Aggregate @PKR1000/Ton = 1000*95.5 = 95,700 PKR

Combined cost of the asphalt plant and equipment of 100 ton of HMA = 5,50,000 PKR

Total cost of 100 ton of HMA = (8,17,000+95,700+5,50,000) = 14,62,700 PKR

Cost of HMA per ton = 1462700/100 = 14627 PKR

Total cost of 1Km section of road section using virgin asphalt mixture is = 14627*424.8 = 6213550 PKR = 6.21 Million

4.3.3.2 Bitumen with 4% WCO and 12% WRT

Cost evaluation

OBC = 4.3%

Weight of binder in mixture = 3.612 tons

Weight of 4% WCO in binder = 0.04*4.3 = 0.172 tons

Weight of 12% WRT in binder = 0.12*4.3 = 0.516 tons

Weight of aggregate in mixture = 95.7 tons

Cost of Binder @PKR190000/Ton = 190000*3.612 = 686280 PKR

Cost of WCO @PKR 150/litre=150*2831*0.172 = 73039.8 PKR

Cost of WRT @PKR 12/kg = 12*1000*0.516 = 6192 PKR

Cost of Aggregate @PKR1000/Ton = 1000*95.7 = 95,700 PKR

Combined cost of the asphalt plant and equipment of 100 ton of HMA = 550000PKR

Total cost of 100 ton of HMA = (6,86,280+73,039.8+6,192+95,700+462000) = 1323212 PKR

Cost of HMA per ton = 1323212/100 = 13232.12PKR

Total cost of 1Km section of road section using virgin asphalt mixture is = 13232.12*424.8 = 5621004 PKR = 5.62Million

4.3.3.3 Bitumen with 4% WEO and 12% WRT

Cost evaluation

OBC = 4.3%

Weight of binder in mixture = 3.612 tons

Weight of 4% WEO in binder = 0.04*4.3 = 0.172 tons

Weight of 12% WRT in binder = 0.12*4.3 = 0.516 tons

Weight of aggregate in mixture = 95.7 tons

Cost of Binder @PKR187000/Ton = 190000*3.612 = 686280 PKR

Cost of WCO @PKR 100/litre=100*2831*0.172 = 48693.2 PKR

Cost of WRT @PKR 12/kg = 12*1000*0.516 = 6192 PKR

Cost of Aggregate @PKR1000/Ton = 1000*95.7 = 95,700 PKR

Combined cost of the asphalt plant and equipment of 100 ton of HMA = 462000 PKR

Total cost of 100 ton of HMA = (6,75,444+48693.2+6,192+95,700+462000) = 1298865 PKR

Cost of HMA per ton = 1298865/100 = 12988.65 PKR

Total cost of 1Km section of road section using virgin asphalt mixture is = 12988.65*424.8 = 5517579 PKR = 5.51 Million

The difference between the construction cost of virgin HMA and waste materials per kilometre per lane (3.6 m) for a 5 cm thickness of road section is presented in Figure below which shows that, in addition to other advantages like enhanced characteristics and environmental advantages, that waste material will lead to cost savings during construction.

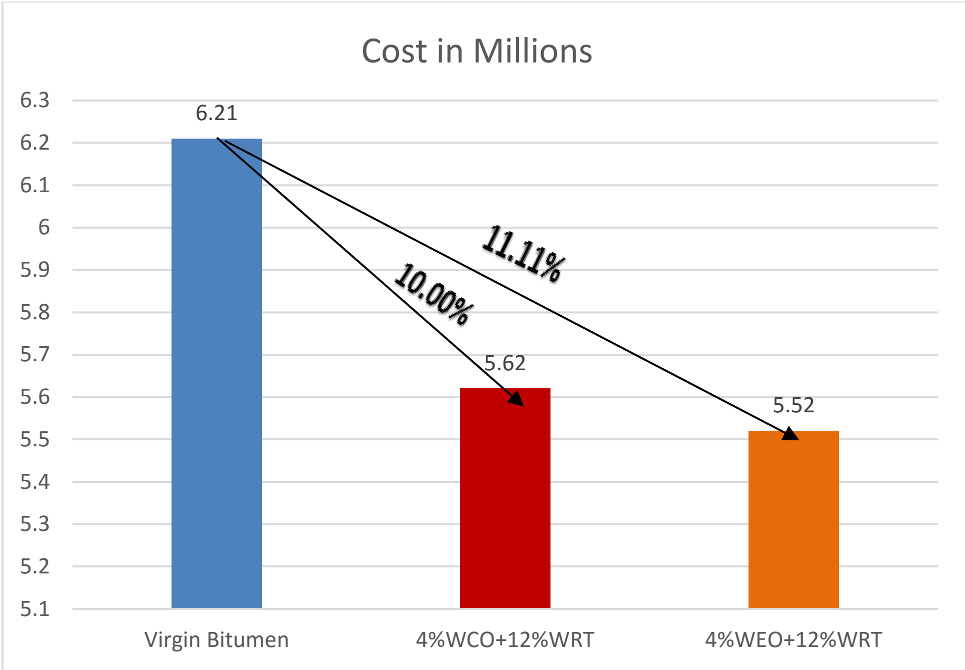

Figure 4-13 Cost comparison of virgin and replaced bitumen

Summary

In this chapter, all the aggregates and bitumen test results have been produced in graphical form. And all the results of physical properties of bitumen using waste materials (WCO, WEO and WRT), viscosity test of the optimum blend, Moisture Susceptibility analysis of asphalt using indirect tensile strength test and Mr value are presented, respectively. In the end, the tensile strength ratio is presented (in tabular and graphical form) against each sample. Also, the cost analysis of virgin bitumen for a 1km road of HMA and with replacement of waste material is calculated.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Summary

The research is carried out to determine the effects use of waste material (WCO, WEO and WRT) by replacing bitumen in HMA mixes. The 60/70 grade of bitumen is used and optimum binder content for a different proportion of waste material in HMA mixes was determined. To observe the effect of waste in HMA mixes, performance tests were conducted on specimens produced by natural aggregate material and that made with building waste material. The key findings after the performance test are discussed in this chapter.

5.2 Conclusions

After conducting comprehensive laboratory testing, the behaviour of asphalt mixes prepared using different proportions of WCO, WEO and WRT in place of virgin bitumen was observed. The following conclusion was drawn.

All physical and performance test result shows that about 16% of bitumen can be replaced with WCO or WEO and WRT powder. The incorporation of this waste into bitumen will solve the disposal problem and will also help in protecting the environment, by minimizing, hazardous fume releases from bitumen and disposal of waste which also causes environmental problems.

As compared to virgin bitumen, modified bitumen with 4% WEO and 12% WRT shows remarkable resistance against moisture susceptibility which can be attributed to the presence of tire rubber.

Modified bitumen shows good resistance to fatigue cracking than virgin bitumen. It is attributed to the presence of waste cooking oil and tire rubber powder which both increase the elastic recovery potential of bitumen.

It also shows that waste cooking oil has better performance results than waste engine oil used in presence of waste rubber tires.

Cost analysis of virgin and modified bitumen shows that the use of modified bitumen is both economical and environmentally friendly. It can decrease bitumen cost used per kilometre by 10-15%

5.3 Recommendations

This research study aims to obtain modified bitumen by replacing a certain percentage of bitumen with waste cooking oil, waste engine oil and waste tire rubber powder thus helping in protecting the environment by incorporating waste material into a useful product.

In this research work, modified bitumen has been assessed through performance and physical testing.

Resilient modulus test results were calculated on 25^{o}C temperature, while it cal also be checked against different temperatures.

This research can also be carried out by incorporating RAP material in it.

Only two of the performance tests are carried out in this study other performance tests like dynamic modulus, creep test, four-point bending etc. should be conducted to completely characterize the behaviour of mix containing waste oil with waste rubber

The focus of new research studies should be to use this modified bitumen in asphaltic pavement and carry out performance testing such as Rutting, Fatigue, Marshall Stability, and flow test.

This topic holds a great deal of potential in research and can be utilized by students in future studies. One can speculate about this research area being open for further research and holds promises of profound knowledge and new findings.

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